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Habitat selection by East Caucasian tur (*Capra cylindricornis*)

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Abstract

Habitat selection by East Caucasian tur (*Capra cylindricornis*), a species of global conservation concern, was examined in relation to terrain, climate and degree of human disturbance using a Geographical Information System and logistic regression. The study area was in the part of the Greater Caucasus of Georgia, where the species protection was not enforced. Two models of tur habitat requirements were obtained: one model at a scale of 20×20 m plots, and the other one at a scale of different habitat fragments made up of 20×20 m plots identified by the first model at its optimal cut-off value. The second model refined the first one.

The first model suggested that the probability of a 20×20 m plot being part of tur habitat was positively correlated with slope, distances to roads and livestock summer camps, and negatively correlated with human population density and annual rainfall. The probability had a bell-shaped correlation with elevation, reaching its maximum at 3008.4 m. The second model suggested that a fragment of a land made up of 20×20 m plots with optimal characteristics for tur occurrence was more likely to contain tur if the area of the fragment was larger and its distance to the nearest area where tur occurred was shorter.

The results show that the occurrence of East Caucasian tur is affected by climate, terrain, human disturbance and habitat fragmentation, and can be predicted regardless of seasonality in the species movements. These models can be applied to the management of the species and its habitat in the areas of the Caucasus that lie at >1000 m asl and have an annual rainfall >600 mm, and where the species protection is not enforced.

Keywords: Caucasian tur; Georgia; The caucasus; GIS; Logistic regression; Habitat fragmentation

1. Introduction

The East Caucasian tur *Capra cylindricornis* Blyth (1841) (hereafter, tur) is a wild goat endemic to the Greater Caucasus. The species is classified as "Vulnerable" globally (Shackleton, 1997; IUCN, 2002). Its range extends from Mt. Shkhara (Georgia) in the west to approximately 10 km east of Mt. Babadag (Azerbaijan) in the east (Vereshagin, 1938; Tsalkin, 1955; Kuliev, 1981). Reliable data on its whole population size has not been established yet (Magomedov et al., 2001). The western edge of the range of the East Caucasian tur remains unclear as the range overlaps with that of the other endemic goat species: West Caucasian tur (*Capra caucasica* Güldenstadt and Pallas, 1783) (Fig. 1). The hybridization zone of these two species is thought to lie somewhere between Mt. Elbrus and Mt. Kazbegi (Tsalkin, 1955; Naniyev, 1958; Heptner et al., 1961; Kotov, 1968; Abdurakhmanov, 1973, 1977). The species generally occurs in steep rocky areas at 1000–4000 m asl (Vereshagin, 1938; Ekvtimishvili, 1952; Chlaidze, 1967; Veinberg, 1984; Weinberg, 2002), though it can descend to 800–900 m in protected areas in the wintertime (Eriashvili, 2000). Tur density increases with the increase in the steepness of the area where the species occurs (Magomedov et al., 2001), and tur population size is limited by the area of undisturbed south-facing slopes that represent winter pastures for turs (Zalikhanov, 1967; Veinberg, 1984; Aiunts and Kolomyts, 1986; Yarovenko, 1997; Magomedov et al., 2001; Weinberg, 2002).

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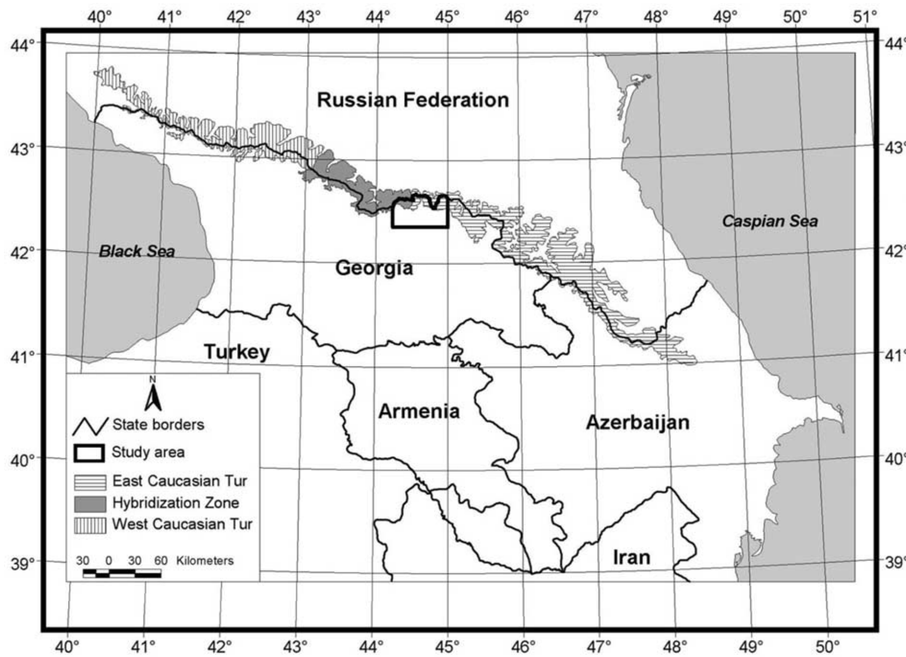

Fig. 1. Ranges of East and West Caucasian turs.

The population of the tur has decreased along with its range since the 1970s (Heptner et al., 1961; Macharashvili, 2000; Veinberg, 1984; Weinberg, 2002). Livestock grazing and human disturbance (especially hunting) have been seen as the main cause limiting the tur in the Caucasus. Tur numbers in Georgia began to reduce in the mid-1970s (Eriashvili, 1990); moreover the species has been extirpated from some areas where it historically occurred such as the gorges of the Intsoba, Chelti, Duruji, Bursa and Mtisdziri Rivers. The Duruji Gorge alone used to support over 1000 heads (Chokheli and Lobzhanidze, personal communication).

Protected areas have proven effective in tur conservation; therefore, these areas supported much higher densities of the turs (Veinberg, 1984; Weinberg, 2002). Unfortunately due to the political, economic and social crisis in the Caucasus, many protected areas fail to enforce protection (Veinberg, 1984; Eriashvili, 2000; Magomedov et al., 2001; Weinberg, 2002). Besides, most of tur range remains outside protected areas. So, strongholds where the turs still survive are an important resource, and understanding the characteristics of these areas is important to the conservation of the species.

In addition to its importance in local folklore and cuisine, the tur plays an important role in maintaining a certain structure of vegetation cover and is one of the primary food items for such rarities as leopard (*Panthera pardus*), lynx (*Felis lynx*), golden eagle (*Aquila chrysaetos*) (Magomedov et al., 2001) and bearded vulture (*Gypaetus barbatus*) (Veinberg et al., 1983; Gavashelishvili and McGrady, 2000). The establishment of well-managed hunting is seen as an effective way of protecting the tur and supporting the local economy (Macharashvili, 2000; Magomedov et al., 2001).

This study examines habitat selection by the East Caucasian tur in areas where the species protection against illegal hunting and livestock grazing was not enforced. The main objective was to obtain a mathematical model of habitat variables essential to tur occurrence that would serve as a tool for the management of the species in conservation efforts such as an on-going protected areas development project in accordance with the 1996 Law on Protected Areas System in Georgia. Habitat modeling plays a substantial role in modern ecological research and conservation biology (Scott et al., 2002).

2. Methods

2.1. Study area

The study area encompasses the unprotected population of the tur in Georgia, covering 2064 km^2 at 1000–5000 m asl in the north-central part of the country. It is bounded on the north by the Russian Federation (Fig. 1). The study area intersects both the southern and northern sides of the main ridge of the Greater Caucasus, where the tree line lies at about 2500 m asl, average annual rainfall is >600 mm (Khatiashvili et al., 1989) and the year-round human habitation occurs below 2200 m asl. Higher human habitation (2000–3000 m asl) is represented by summer camps used by shepherds and herders from May through October. Each livestock summer camp usually holds 2–5 people and hundreds of livestock.

2.2. Habitat variables

Maps of the study area were scanned, and geo-referenced, and measurements of the habitat variables were performed using the ArcView v.3.3 GIS software package (ESRI Inc., Redlands, CA). Terrain data were extracted from 1:50,000 topographic maps (Headquarters of Geodesy and Cartography under the Council of Ministers of the USSR. 1978, Facility No. 11). Measures of rainfall were from Khatiashvili et al. (1989). Data on human numbers in populated areas were obtained from inhabitants during fieldwork.

Feature themes (i.e., shapefiles) of 200-mm rainfall contours, 100-m elevation contours, population points, roads, trails, village constructions, livestock summer-camps, and woodland cover were created to derive 20-m interpolated surfaces (grids) of habitat variables (Table 1).

2.3. Sampling

The study area was surveyed for the tur for 10 years, and the area of tur occurrence (hereafter the observed tur occurrence zone) was mapped using a Garmin Etrex 12 Channel GPS Satellite navigation unit (Garmin Corp., Ulathe, KA) regardless of seasonality in the species movements.

The study area was overlaid with a point theme where points were 500 m away from one another to avoid cluster sampling. The points that fell within the observed tur occurrence zone were assigned values of 1 and the rest of the points outside the zone were assigned values of 0. Then, values from the grids of the habitat variables were extracted for each point in the point theme.

2.4. Statistical treatment

Statistical analyses were performed using SPSS v.11 for Windows (SPSS Inc., Chicago, IL). Binomial logistic regression was used to predict habitat requirements for the tur because the dependent variable (the tur present or absent) was dichotomous (Hosmer and Lemeshow, 1989; Menard, 2002). Logistic regression estimates parameters (coefficients) after transforming the dependent variable into a logit variable:

$$\ln[p/(1-p)] = B_0 + B_1X_1 + B_2X_2 + \cdots$$

where ln is the natural logarithm, p is the probability of obtaining a positive response (in our case, the tur presence), $B_0, B_1, B_2, \ldots$ are parameters to be estimated from the observed data, and $X_1, X_2, \ldots$ are the independent (i.e., explanatory) variables.

The forward stepwise likelihood ratio method was used to select variables that were included in each step using the level of $P = 0.05$ for entry and $P = 0.10$ for removal. Models produced by the initial logistic regression procedure were improved through residual analysis, and distilled to the best-fit model using a model evaluation procedure.

Residual analysis was performed obtaining:

(a) Scatter plots of standardized residuals against the independent variables, which was examined to see if the independent variables in the model were linearly related to the logit of the dependent variable. Quadratic, cubic, square root, logarithmic and inverse transformations were tested to eliminate nonlinearity.

Table 1
Habitat variables used to obtain models of tur occurrence

Variable	Description
Measured at a scale of 20 × 20 m cell	
Rainfall	Average annual rainfall (mm) interpolated using the script: Contour Gridder (Stuckens, 2003)
Elevation	Elevation (m) above sea level interpolated using the script: Contour Gridder (Stuckens, 2003)
Slope	Slope (°)
CosAspect	Aspect cosine transformed (i.e., increasing from south (−1) to north (+1)
SinAspect	Aspect sine transformed (i.e., increasing from west (−1) to east (+1)
PopDensity	Human population density (people per km^2). Each cell in the grid has a density value calculated within 2 km of the cell center using the Kernel function
DstRoad	Distance to roads (km). The value of every cell in the grid is its distance to the nearest point of roads
DstTrail	Distance to trails (km). The value of every cell in the grid is its distance to the nearest point of trails
DstVillage	Distance to villages (km). The value of every cell in the grid is its distance to the nearest point of human settlements
DstCamp	Distance to livestock summer-camps (km). The value of every cell in the grid is its distance to the nearest point of livestock summer-camps
Woodland	Wooded area with cell values of 1 and 0 for woodland and no woodland, respectively
Measured at a scale of habitat fragments	
Area	Area of a predicted habitat fragment (km^2)
DstTur	Shortest distance of a predicted habitat fragment to the nearest area where the tur occurs (km)

(b) Scatter plots of leverage values (a measure of how much a case influences the regression) and Cook's distances (a measure of how much the coefficients change when a case is removed from the model) were examined to reveal possible errors in the data. Cases with leverage values $> 2p/n$, where p is the number of independent variables in the model, n is the number of cases were examined more closely, as were cases with Cook's distances >1.

To select the best-fit model and optimize its classification cutoff value, the Receiver Operating Characteristic (ROC) Curve was tested. One of the ROC Curve characteristics is the Area Under the ROC Curve (AUC). AUC values of 1 suggest the classification to be correct, values of 0 suggest it to be incorrect, and values of 0.5 suggest that the scheme is no better than guessing. To evaluate a measure of the agreement between the observed values and predicted group values at an optimal cutoff value, Cohen's kappa was used, in which a value of 1 indicates perfect agreement, while a value of 0 indicates that agreement is no better than chance.

The best-fit model obtained at a scale of 20-m cells was applied to the study area, which generated a predicted tur occurrence zone using the optimal cutoff value of the model. To check for habitat fragmentation effects on tur occurrence and refine the results of the model, the presence/absence of the tur in fragments of the predicted tur occurrence zone was regressed on an area of a fragment, its distance to the observed tur occurrence zone and its mean values of the habitat variables measured at a scale of 20-m cells.

3. Results

In all, 8212 evenly distributed points for tur occurrence were obtained, of which the tur was present at 1685 points and absent at 6527 points. The observed tur occurrence zone covered 410.16 km^2 within the study area. The best model excluded aspect and distances to trails and villages. The transformation of population density into a logarithm variable and elevation into a quadratic variable significantly improved the model. With the inclusion of the quadratic function of elevation in the model, woodland negatively correlated with tur occurrence was no longer significant (Table 2). The quadratic function of elevation reached its maximum at 3008.4 m. The scatter plot of leverage values and Cook's distances did not reveal influential points. ROC plot test suggested that the model performed better than guessing ($\mathrm{AUC} \pm \mathrm{SE} = 0.975 \pm 0.001$, $P < 0.001$) and its optimal classification cutoff was 0.3 (i.e., if the probability of a 20-m cell being part of tur occurrence zone >0.3, the prediction was that the tur would occur in the cell). At this cutoff, the model classified correctly 89.0% of cells with the tur present and 93.3% of cells where the tur did not occur. Overall, the model classified correctly 92.4% of all cells. The model performed better than chance (Cohen's $\mathrm{kappa} \pm \mathrm{SE} = 0.780 \pm 0.008$, $P < 0.001$).

The analysis of habitat fragments (Fig. 2) identified by applying the above model at its optimal cutoff value of 0.3 to the study area produced the best-fit model that included only an area of a fragment and its distance to the observed tur occurrence zone. The residual analysis did not reveal influential points. The respective ROC

Table 2
Model for predicted occurrence zone of tur, using binomial logistic regression

Model	Parameter estimate	Standard error	Wald	P
Habitat requirements at a 20-m cell scale				
Slope	0.059	0.004	185.998	<0.001
DstCamp	0.938	0.033	804.470	<0.001
DstRoad	0.576	0.031	345.759	<0.001
Elevation	22.226×10^{-3}	1.176	357.291	<0.001
(Elevation)^2	-3.694×10^{-6}	0.198	348.222	<0.001
Rainfall	−0.008	<0.001	625.210	<0.001
ln(PopDensity+1)	−1.051	0.149	49.882	<0.001
Constant	−32.463	1.721	355.682	<0.001
df	1			
2 Log likelihood	−2742.033			
Nagelkerke R^2	0.775			
Habitat requirements at a fragment level				
ln(Area)	1.345	0.520	6.687	0.01
ln(DstTur)	−3.075	1.126	7.460	0.006
Constant	−2.504	1.190	4.424	0.035
df	1			
2 Log likelihood	−19.484			
Nagelkerke R^2	0.731			

Human population density, fragment area and distance to the nearest area with tur occurrence are log-transformed, and there are two variables of elevation, one of which is squared.

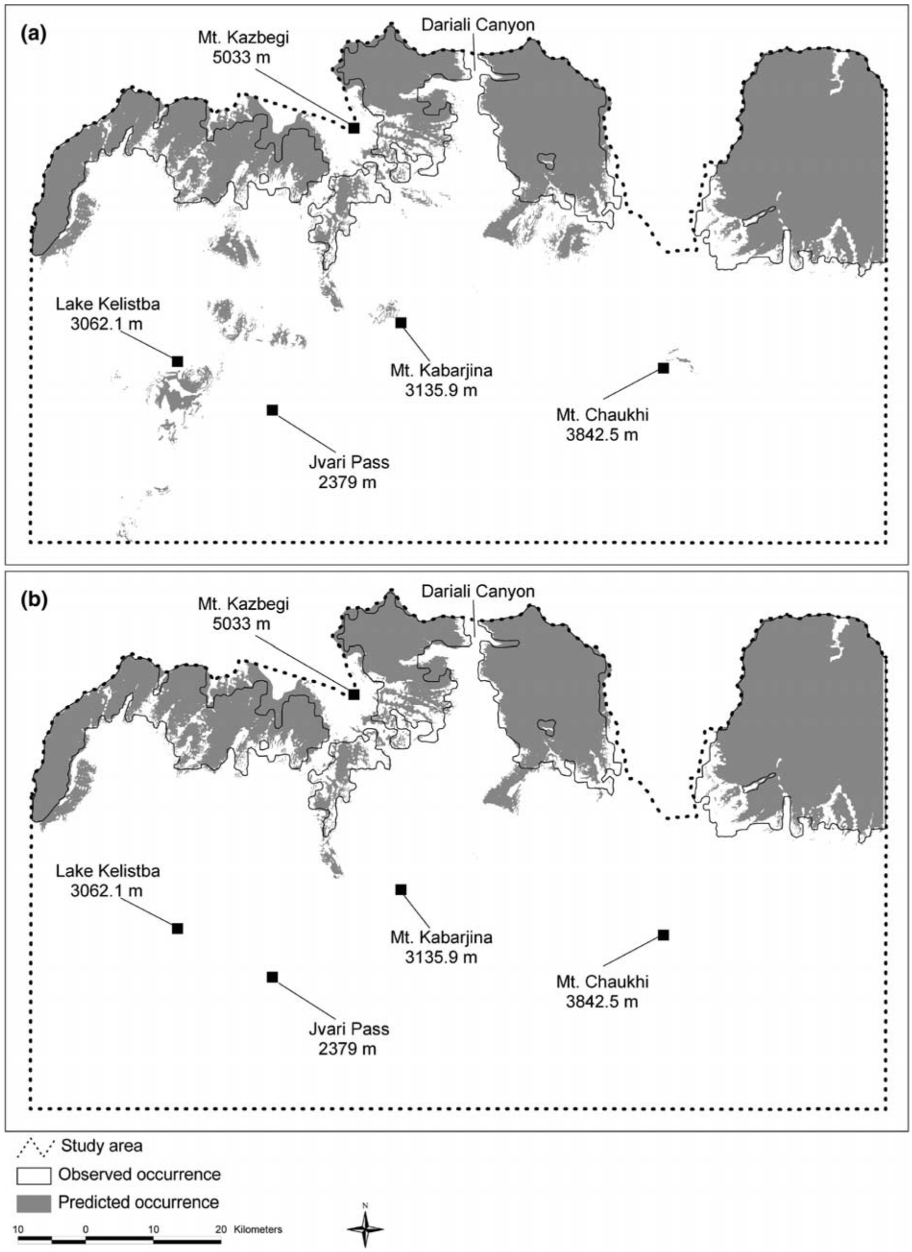

Fig. 2. Maps of predicted tur occurrence: (a) generated by the model estimated at a scale of 20×20 m plots at its optimal cutoff value of 0.3; (b) refined by the habitat fragmentation model at its optimal cutoff value of 0.5.

plot suggested good performance ($\mathrm{AUC} \pm \mathrm{SE} = 0.943 \pm 0.037$, $P < 0.001$) and its optimal classification cutoff value of 0.5. At this cutoff, the model classified correctly 78.6% of habitat fragments with the tur present and 95% of habitat fragments where the tur did not occur. Overall, the model classified correctly 88.2% of all habitat fragments. The model performed better than chance (Cohen's $\mathrm{kappa} \pm \mathrm{SE} = 0.752 \pm 0.115$, $P < 0.001$). The application of this model to the study area considerably increased the prediction accuracy (Fig 2).

Thus, the first model suggested the importance of climate, terrain and human disturbance and the second one showed that tur occurrence was affected by habitat fragmentation.

4. Discussion

This study is the first of its kind to work out a model that can predict the range of tur distribution in relation to a set of various habitat variables. Furthermore, it is the first to use a systematic, grid-based approach to analyze spatial patterns of the species distribution. The advantage of the maps that can be derived from the model is that they provide the predictions of the statistical model in a way that is clearer and easier to interpret.

A positive response of the model to slope may be explained by the tur's preference for rocky areas that tend to be steeper, and less accessible to humans and terrestrial predators. Although not documented within the study area, predation from wolf (*Canis lupus*) in Daghestan (the Russian Federation) has a considerable impact on tur numbers and distribution as well as the sex ratio in the population (Abdurakhmanov, 1973; Akhmedov and Magomedov, 1996; Magomedov et al., 2001).

A quadratic (bell-shaped) response to elevation (a response maximum at 3008.4 m) indicates that the tur avoids the lower elevations, perhaps because of human disturbance, and the higher elevations because of harsh climate and poor food base (Veinberg, 1984). Also, at lower elevations where human disturbance is minimal usually dense woodland replaces grassland that constitutes the major food base for the turs (Magomedov et al., 2001).

The negative relationship of the tur with average annual rainfall in the model could be accounted for by: (a) increased snowfall limiting access to food especially in the wintertime; (b) smaller areas of such tur habitat characteristics as rockiness that seems to give way to dense tall vegetation cover and woodland as annual rainfall increases. Yet, within the same elevation range where annual rainfall varies from below 600 mm up to 1000 mm in Daghestan (the Russian Federation), the relationship of the tur and rainfall is thought to be just the opposite because of water scarcity and poor food base in areas of low annual rainfall (Magomedov et al., 2001). Thus, the model for a wider annual rainfall range could have a bell-shaped response to an annual rainfall with a response maximum near 600 mm.

Livestock summer-camps are source of disturbance caused by the presence of livestock, dogs and herdsmen in the summertime. Even though these areas are empty of humans and livestock in the wintertime, overgrazed grassland as well as artifacts (e.g., cabins and other man-made constructions) keeps the turs away.

That human population density in tur habitat matters more than proximity of populated areas probably occurs because population density better accounts for the extent to which the habitat is exploited and disturbed by humans. For the same reason proximity of roads (i.e., vehicular access) performs better than that of trails in the model.

The shift of the turs especially females with their kids and immature males to northern slopes in the summertime (Magomedov et al., 2001) may explain unimportance of aspect to the species overall occurrence zone.

5. Conservation implications

Provided a GIS coverage of the habitat variables, this model can be applied to other areas of the Caucasus to: (a) predict possible tur occurrence zone; (b) identify areas where previously unknown areas might be located; (c) highlight areas where the turs may occur in the future if the population grows due to conservation activities. The model will define which areas are best suited to major tur conservation efforts. To do so, the only manageable variables in the model will be anthropogenic ones: human settlements, roads and livestock summer-camps whose development should be either stopped, rerouted or not planned in the predicted tur occurrence zone. In order to enlarge tur habitat, the only variable that can be realistically managed will be livestock summer-camps. The removal or relocation of livestock summer-camps from areas where they have been illegally established should be an immediate step. Alternative areas or ways of income should be sought to reduce the legally and historically established livestock summer-camps. Thus, the model will be helpful to the zoning of infrastructure, hunting, land-use, and recreation/tourism in favor of the East Caucasian tur. Zoning plays an important role in avoiding conflicts between nature conservation and other activities. In Georgia the importance of the grid-based zoning for providing secure spatial opportunities for the survival of some species including bezoar goat (*Capra aegargus*) is demonstrated in the proposed Tusheti National Park (Gokhelashvili et al., 2002).

Furthermore, This model will enable a better estimation of the species population size given the difficulty and costs of census related to extreme terrain and climate. For example, the information on tur densities (Veinberg, 1984; Magomedov et al., 2001; Weinberg, 2002) and an area of modeled habitat could be used to estimate the species population size in different parts of the Caucasus. Based on the population estimates and genetic variability, the next step would be to define the species viability.

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